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The role of renewable versus non-renewable energy to the level of CO_2 emissions a panel analysis of sub- Saharan Africa's Big 10 electricity generators

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ABSTRACT

Undoubtedly, the increasing rates of CO_2 emissions contribute highly to climate change. Studies stress the importance of understanding the determinants of emissions, in order to implement appropriate policies. In the past, literature only looked at the effect of aggregate energy to emissions; while nowadays, with the increasing role of renewables, they aim at evaluating the impacts of renewable and non-renewable energies separately. Also, studies ignored possible cross-dependence among countries; concept particularly important for countries linked by trade or geographical position. Also, only lately, studies focused on developing economies.

In this study, we aim to address these gaps of the literature by estimating the determinants (renewable and non-renewable energy, income and trade openness) of CO_2 emissions for the ten biggest electricity generators in Sub-Saharan Africa for the period 1980 to 2011 by employing panel estimation techniques robust to cross dependence. A long-run relationship between the main variables is confirmed. Increases in non-renewable energy consumption intensify pollution while the opposite holds for renewable energy. With regards to direction of causal relationships, we observe a unidirectional causality running from emissions, income, trade and non-renewable energies towards renewable energies; from non-renewable energy to emissions; and from emissions and non-renewable energies to trade.

1. Introduction

Due to recent developments, climate change unfortunately is not just a threat in theory and only in the future anymore recently. It is the result of numerous of decades of polluting the atmosphere and the planet without taking into account the consequences. The world has been witness to increasingly growing demands for energy due to higher levels of economic production but also high population growth [1]. The atmospheric emissions or greenhouse emissions (GHG), and particularly the CO_2 emissions, are the result of such type of production and consumption internationally. They are related with energy consumption, economic growth and the environment. Their effects are demonstrated in the dangerous conditions for the human race of temperatures, sea levels, and air pollution [2].

As discussed in the literature [3–8], significant actions (with regards to energy technology choices, supply mix choices, policy changes but most of all, shift in behavior and mentality) need to be taken to avoid an environmental disaster. The International Energy Agency [9,10]; agrees with the notion that the current path is not sustainable in its three pillars: economic, social and environmental. So, all agree that decisive actions and strict policies should take place to reverse the negative environmental consequences of air pollution. To do so, many countries have turned their efforts towards substituting fossil fuel energy generation (that is considered the primary reason for the increasing air pollution) to renewable cleaner alternatives, as well as improving the efficiency of energy usage [11] without influencing their economic growth and development.

Renewable energies are considered one of the most viable solutions to improve the environmental status quo of our planet and mitigate and abate the emissions of GHG [12] without affecting the countries' economic growth and development. On the contrary, it is argued [13] that renewable energies contribute to the economic

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conditions of countries. The use of non-hydro renewable energies shows the fastest rates of increase in power generation [14]. According to IEA [15]; by 2040, renewables-based generation reaches a share of 50% in the European Union, around 30% in China and Japan, and above 25% in the United States and India: by contrast, coal accounts for less than 15% of electricity supply outside of Asia; bringing the share of coal in the global electricity mix to drop from 41% to 30% with non-hydro renewables increasing at a similar rate while gas, hydro and nuclear maintaining their existing shares. It was estimated that renewables were responsible for almost half of the world's new power generation capacity in 2014. In the same report [15], CO_2 emissions from energy generation are estimated to increase at only one-fifth of the rate at which energy output rises to 2040, To illustrate, the importance of this projection, the relationship was one-to-one over the last 25 years. Boluk and Mert [16] also show that "renewable energy consumption contributes around ½ less per unit of energy consumed than fossil fuel energy consumption in terms of GHG emissions in EU countries".

The relationship between emissions and income specifically has attracted particular attention, being described by the Environmental Kuznets Curve (EKC) hypothesis. According to this hypothesis, the relationship between the income and pollution levels (or environmental degradation) takes the shape of an inverted-U curve: at initial stages of development, the pollution levels increase as the country grows but after reaching a particular threshold of development, the pollution levels tend to decrease. In other words, it is expected that the environmental quality of an economy worsens first before it improves with the economic growth. Studies have initially focused only on the bivariate causal link but the literature recently has seen a flood of studies including energy consumption (as an in-between variable to explain and clarify the bivariate causality) to conduct a trivariate evaluation as well as numerous studies that have included various control variables to capture specific characteristics of the economies examined, such as trade openness. As per recent empirical studies [17–20], we propose that trade openness also explains fluctuations in emissions, through composition, scale and technique effects.

[1,21,22]; on the other hand argues that the EKC hypothesis does not hold for the poor countries, because they have not most probably reached the threshold income level for the emission levels to start decreasing. Another explanation for this is the nature of the developing or poor countries that are abundant in fossil fuel resources and hence, power generation from particularly coal is cost-effective. Hence, the transition to renewable energies and the "right-hand side of the EKC" (leapfrogging) is challenging for developing countries, or as Murphy [23] points out especially for the rural East Africa. Ben Jebli et al. [24] examined the existence of the EKC for all the sub-Saharan African countries and confirmed that the hypothesis cannot be supported for this group of countries: exports cause emissions to increase, and imports to decrease.

In addition, African countries have to deal with immediate problems of declining power systems in combination with significant lack of access to energy for most of the rural areas. This is another reason why environmental friendly policies were not a priority in the agenda of African countries.

However, due to the volatility of oil and gas prices, these countries do update their energy strategies for the future giving special attention to renewable energies to take advantage of their abundance of natural resources and the opportunity to give access of energy to remote rural areas, without having to extend the national grid [25]. Another reason for the effort of the African countries to focus on renewables towards a future reduction of emissions is the vulnerability of African economies to climatic changes. The economies are based on traditional, primarily agricultural, production that would be among the first ones negatively affected by changes in weather and temperature levels. Nakumuryango and Inglesi-Lotz [13] show that African countries' renewable energy consumption, production and intensity have shown increasing rates during the last two decades with high share of hydro energy due to the continent's resources.

The main purpose of our study is not only to investigate the causal relationships between CO_2 emissions, energy consumption and economic growth in Sub-Saharan Africa but also, to decouple the importance of renewables and non-renewable energies to CO_2 emissions. The study focuses especially to the Big 10 electricity generators of the African continent and among the strongest economies in the continent in order to test the EKC hypothesis for them. The reason for this is because these countries might have either reached certain levels of development or income thresholds and might confirm the EKC hypothesis. Also, these are the countries that due to their dependence primarily on fossil fuels, they have considerable levels of emissions. For this purpose, this study follows panel estimation techniques that consider heterogeneity and cross-sectional dependence in the panel so as to obtain consistent and reliable estimation results.

The rest of the paper is organized as follows. The next section provides a brief survey of the current literature. The third section describes the model and the data used, while subsequently, we present the specific econometric techniques and the empirical results. The final section concludes and discusses the findings' policy implications.

2. Literature review

This difficult balance between energy consumption, economic growth and emissions intrigued numerous researchers internationally. The nexus between energy and economic growth as well as the trivariate relationship between these two variables and environmental pollution has been studied extensively in the literature. Although a number of studies attempted to gather consensus in the existence and direction of causality, the findings remain inconclusive and highly dependent on the time period examined, the group of countries, and the techniques employed [2].

The relationship between the pollution level and economic growth and development (income) described by the EKC hypothesis has been extensively investigated in the literature. However the majority of the studies focus on developed economies (for example Soytas et al. [26] for US, Ang [27] for France, Al-Mulali et al. [1,21,22]; for European countries) that are expected to have passed their threshold levels. Recently, the focus shifted to developing economies as well (Al-Mulali et al. [28] for the Latin American countries, Ang [29] for Malaysia, Apergis and Payne [30] for various emerging market economies). The idea that underpins many of the studies is that even for countries that appear to be at the left-hand side of the inverted-U shaped EKC curve, with the appropriate policies they can "pass" to the right-hand side before reaching high levels of development. Kivyiro and Arminen [31] examine the relationship between energy consumption, economic growth and the emissions in six Sub-Saharan African countries. They showed that for these countries all factors Granger cause CO_2 emissions. Destek and Ozsoy [32] confirmed the EKC hypothesis for Turkey, for example, concluding that energy consumption and economic growth resulted in environmental degradation but also, globalization decreases the CO2 emissions. Sugiawan and Managi [33] also confirmed the EKC hypothesis for Indonesia for the period 1971–2010.

The literature also examined the impact of trade to the environment [34–37] are some examples). Increased trade (especially exports) is linked to higher income levels and hence improvement in the environmental quality and certainly in the availability of

alternative technologies to generate energy in a more environmental friendly manner (known as the technique effect, Cole [38]. Higher levels of trade openness among all countries will intensify the production of goods and services where each country has a comparative advantage and hence, more efficient production technologies that might result in more energy efficient ones too. Le et al. [39] studied the interlinkages between trade openness and various emissions of particulate matter (PM10). Their results shows that increased trade openness is linked with environmental degradation but the findings differ depending on the countries' income (positive effect in high-income and damaging in middle- and low-income countries). Shahbaz et al. [40] confirmed a feedback effect between trade openness and CO2 emissions for the world and the middle-income countries, while trade openness causes emissions for the high-income and low-income countries.

Methodologically, studies in the literature are divided between the ones that use one-country time series econometric techniques ([41,26,42,19,32,43–49,33,50] and those that look at country groups and employ panel data techniques [51–57,16,58]. Extensive summaries of the literature on the topic can be found in Al-Mulali et al. [1]; Al-Mulali et al. [21]; Bilgili et al. [59]; Dogan and Seker [60] and Dogan and Seker [61]. However the majority of the panel studies until recently used conventional panel estimation techniques (such as the Im-Pesaran-Shin (IPS) and the Levin-Lin-Chu (LLC) unit root tests, the Johansen or the Pedroni cointegration tests, and the pairwise or the Vector Error Correction Model (VECM) based Granger causality methods). New generation of panel techniques and tests take into consideration of cross-sectional dependence and heterogeneity attributes of the panel, making the results more robust (see Refs. [61,62]. Hence, our study here aims at following the latest strand of the literature for the group of the top 10 electricity generator countries in the Sub-Saharan Africa. The specific panel has not been used in the energy-growth –pollution literature before.

3. Model and data description

By following the recent studies by Bilgili et al. [59]; and Dogan and Seker [60]; this study uses the EKC model in equation (1) wherein real income (GDP), renewable energy (REN), non-renewable energy (NREN) and trade openness (TO) are the determinants of carbon dioxide (CO_2) emissions in the top 10 African countries:

$$\ln CO_{2\,it} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln GDP^2 + \beta_3 \ln REN_{it} + \beta_4 \ln NREN_{it} + \beta_5 \ln TO_{it} + \varepsilon_{it} \quad (1)$$

wherein i and t represent country and time period; ε is the normally distributed error term; β_i (i = 1,2,3,4,5) are the coefficients on real income, the quadratic real income, renewable energy, non-renewable energy and trade openness, respectively. Since the data used through empirical analysis are converted into their natural logarithmic, the coefficients are also equal to the long-run elasticities of carbon emissions with respect to real output, renewable and non-renewable energy and trade openness.

In regard to data description, CO_2 emissions are in thousand tons, real income is the real gross domestic product (GDP) constant 2005 US dollars, renewable energy is electricity production from renewable sources (i.e. wind, solar, hydropower, geothermal and biomass) in billion kilowatt-hour (kWh), non-renewable energy is electricity production from non-renewable sources (i.e. coal, oil and natural gas) in billion kWh, trade openness is the ratio of foreign trade to GDP. The data cover the period 1980–2011. The data for CO_2 emissions, GDP and trade openness are sourced from the World Development Indicators (data.worldbank.org), and the data for electricity production are sourced from the U.S. Energy Information Administration (www.eia.gov).

Table 1
Descriptive statistics.

	Mean	Std. Dev.	Minimum	Maximum	Observations
CO_2	62.84	109.1	0.57	477.80	320
GDP	53.77	62.9	1.87	309.8	320
REN	4.19	4.38	0.02	16.78	320
NREN	27.48	52.48	0.01	233.05	320
TO	57.38	20.54	6.32	116.04	320

The top 10 countries, ranked according to their total electricity generation in 2012, are Algeria, Egypt, Ghana, Morocco, Mozambique, Nigeria, South Africa, Sudan, Tunisia and Zambia.[1] Referring to the descriptive statistics in Table 1, South Africa was the largest carbon emitter with 477 thousand tons in 2009 and had the largest real income with 309 billion US dollars in 2011; Nigeria was the smallest carbon emitter with a half thousand tons in 1980 and Ghana produced the smallest real output in 2000; Sudan was the largest consumer of renewable energy with 16 billion kWh in 2004 while Algeria was the smallest consumer of renewable energy with 0.02 billion kWh in 2004; Morocco was the largest consumer of non-renewable energy with 233 billion kWh in 2005 while Sudan was the smallest consumer of non-renewable energy with 0.01 billion kWh in 2004; Zambia was the most open country in 2010. Large standard deviations of the analyzed variables suggest that data points are far from the mean. This implies that there is enough variability to work with this panel time-series data.

4. Methods and empirical findings

4.1. Heterogeneity and cross-sectional dependence

This study firstly investigates whether or not heterogeneity and cross-sectional dependence exist across countries in the panel in order to apply appropriate estimation techniques. In other words, panel estimation methods that do not take into account heterogeneity and cross-sectional dependence may report erroneous output in case that the panel time-series data are not homogenous and cross-sectionally independent. In order to check for the presence of cross-sectional dependence for carbon emissions, real income (the quadratic real income, renewable and non-renewable energy, and trade openness across the top ten power generators, this study uses the cross-sectional independence test (CD-test) developed by Pesaran [63].

Results from the CD-test posted in Table 2 show that we have sufficient evidence to reject the null hypothesis of cross-sectional independence for each panel time-series data at 1% level of significance. This implies that the analyzed variables are cross-sectionally dependent across countries in the panel.

Table 2
Results from cross-sectional independence test.

	$\ln CO_2$	$\ln GDP(\ln GDP^2)$	lnREN	lnNREN	lnTO
CD-test	16.96*	36.33*	10.16*	29.09*	9.53*
p-value	0.00	0.00	0.00	0.00	0.00

Note: * denotes the statistical significance at 1% level.

[1] In the ranking, Libya was ranked in the top10 electricity generators in the African continent; however the data availability for the country was from poor to non-existent for some variables. Hence, the decision was to include in the group the 11th ranked country "Sudan and South Sudan".

Table 3
Results from homogeneity tests.

Test	lnGDP(lnGDP^2) lnREN	lnNREN lnTO
$\tilde{\Delta}$	22.39* 14.21*	27.21* 8.16*
$\tilde{\Delta}_{adj}$	22.49* 14.90*	28.53* 8.56*

Note: * denotes the statistical significance at 1% level.

In the second stage, this study employs the slope homogeneity test proposed by Pesaran and Yamagata [64] estimates the delta ($\tilde{\Delta}$) and the adjusted delta ($\tilde{\Delta}_{adj}$). Results from the homogeneity tests are reported in Table 3. We have enough evidence to reject the null hypothesis of slope homogeneity in favor of the alternative hypothesis of slope heterogeneity for the analyzed variables at 1% level of significance. Thus, it can be asserted that the panel time-series data are heterogeneous for the top African countries. Overall, we can conclude that cross-sectional dependence and heterogeneity exists across the analyzed countries for carbon emissions, real income, renewable energy and non-renewable energy and trade openness.

4.2. Panel unit root tests

Because heterogeneity and cross-sectional dependence appear in the data, we should proceed with panel unit root tests that consider the issues of heterogeneity and cross-sectional dependence in the procedure. This study uses the cross-sectionally augmented Dickey-Fuller (CADF) and the cross-sectionally augmented Im-Pesaran-Shin (CIPS) panel unit root tests developed by Pesaran [65]. They are both strong to the presence of the mentioned issues in the variables.

Results from the panel unit root tests are reported in Table 4. Because we have insufficient evidence to reject the null hypothesis of unit root for all variables at their levels at 1% level of significance, we can assert that they are non-stationary at levels. On the other hand, the analyzed time-series become stationary at their first-differences since the null hypothesis of unit root can be rejected for first-differences. Overall, carbon emissions, real income, the quadratic real income, renewable energy, non-renewable and trade openness are, I (1), integrated of order one.

4.3. Panel cointegration tests

In order to obtain statistically and economically meaningful coefficient estimates, the analyzed variables must be either stationary or cointegrated at their levels. As it is the case that the analyzed panel time-series are not stationary at levels, panel cointegration test must be further employed. Besides, panel cointegration test selected should take notice of heterogeneity and cross-sectional dependence. This study, therefore, apply Kao panel cointegration test strong to the presence of heterogeneity only [66] and the LM bootstrap cointegration test robust to both heterogeneity and cross-sectional dependence [67].

Table 4
Results from panel unit root tests.

	Level	First difference		
	CADF	CIPS	CADF	CIPS
$lnCO_2$	−2.69	−3.41*	−4.47*	−6.01*
lnGDP(lnGDP^2)	−2.82	−2.62	−3.32*	−4.73*
lnREN	−2.68	−2.80	−3.67*	−5.57*
lnNREN	−2.6	−3.21*	−3.80*	−5.17*
lnTO	−2.52	−2.65	−4.52*	−5.46*

Note: * denotes the statistical significance at 1% level.

Referring to results from the Kao panel cointegration test in Table 5, the analyzed variables are cointegrated since we have enough evidence to reject the null hypothesis of no cointegration in favor of the alternative hypothesis of cointegration at 1% level of significance. According to results obtained from the LM bootstrap panel cointegration test shown in Table 5, we have insufficient evidence to reject the null hypothesis of cointegration at 1% level since the respective p-value is far greater than the significance level. Both panel cointegration tests confirm that CO_2 emission, real income, the square of real income, renewable and non-renewable energy, and trade openness are cointegrated and thus have a long-run relationship for the top 10 electricity generators in the African continent.

4.4. Estimates of the long-run effects

This study further applies the group-mean DOLS [68] so as to estimate the long run coefficients on real output, the quadratic real output, renewable and non-renewable energy, and openness for CO_2 emissions. Pedroni [69] suggests that the group-mean estimator produce more consistent estimates than the pooled and weighted estimators in case where heterogeneity exists in cointegrated panel data. Besides, Herrerias et al. [70] suggest that the DOLS approach is among the least sensitive estimators to the issue of cross-sectional dependence. Because the analyzed panel data are transformed into their natural logarithm, the coefficient estimates given in Table 6 are also equal to the elasticities of CO_2 emissions with respect to real income, the square of real income, renewable energy, non-renewable energy and trade openness.

Results from the group-mean DOLS estimator are represented in Table 6. Because the panel time-series data are transformed into their natural logarithm, the reported coefficients in the table are equivalent to the elasticities of CO_2 emissions with respect to real income, quadratic real income, renewable energy, non-renewable energy and trade openness. The effects of real output and the square of real output on carbon emissions are negative and positive, respectively. This implies that the EKC hypothesis is not supported for the panel of top 10 energy generators. More precisely, the (partial) marginal effect of real income on the level of emissions is

Table 5
Results from panel cointegration tests.

a) Kao panel cointegration Test		
ADF	test statistic	p-value
	−3.68*	0.00
b) LM bootstrap panel cointegration test		
	test statistic	Bootstrap p-valu
LM bootstrap	8.42	0.94

Note: * denotes the statistical significance at 1% level.
The bootstrap test statistic is computed by stochastic simulations using 5000 replications.

Table 6
Results from group-mean DOLS estimator.

	Coefs.	t-stat	p-value
lnGDP	−18.42**	−3.08	0.00
lnGDP^2	0.41**	3.35	0.00
lnREN	−0.17**	−2.84	0.00
lnNREN	0.34**	3.51	0.00
lnTO	−0.12*	−1.98	0.04

Note: The dependent variable is CO_2 emissions. ** and * denote the statistical significance at 1% and 5% levels.

calculated by $\beta_1+2^*\beta_2^*GDP$ ($-18.42 + 2^*0.41^*GDP$), and thus the (partial) marginal effect of real output on the pollution is clearly negative at early stages of economic growth; but, it increases and eventually becomes positive as the analyzed African countries shifts to higher stages. The lack of the EKC hypothesis is consistent with, Ozturk and Acaravci [71] for Turkey, Pao et al. [72] for Russia, Du et al. [73] for China, Chandran and Tang [74] for ASEAN, Boluk and Mert [16] for the EU, Lopez-Menendez et al. [75] for the EU, Dogan et al. [76] for the OECD countries, Al-Mulali et al. [21] for Vietnam, Al-Mulali et al. [2] for Italy, Farhani and Ozturk [77] for Tunisia, Ozturk and Al-Mulali [78] for Cambodia, and Dogan and Turkekul [20] for the USA.

The elasticities of CO_2 emissions with respect to renewable and non-renewable energy are 0.34% and −0.17%, respectively. This indicates that increases in non-renewable energy consumption increase the pollution while increases in renewable energy consumption drive down environmental degradation. The top 10 Sub-Saharan countries are strongly suggested to stimulate the use of energy from renewable sources and mitigate the use of energy from non-renewable sources so as to reach lower level of emissions. The effects of energy consumption by sources are in line with Chiu and Chang [79,80]; Shafiei and Salim [81]; Lopez-Menendez et al. [75]; Al-mulali et al. [1]; Boluk and Mert [19]; Dogan and Seker [60]; Ben Jebli et al. [58] and Dogan and Seker [61]. Furthermore, the elasticity of carbon emissions with respect to trade openness is −0.12%. This implies that increases in trade openness help reduce the level of CO_2 emissions for the top energy generators in Sub-Saharan Africa. The negative effect of trade openness on the pollution is consistent with Hossain [52]: Sulaiman et al. [80]; Shahbaz et al. [82]; Al-Mulali et al. [22]; Dogan and Turkekul [20]; Ben Jebli et al. [58]; Dogan and Seker [60]; Dogan and Seker [61]. The analyzed countries are strongly advised to boost their openness through several regulations.

4.5. Estimates of the direction of granger causality

The estimates of long-run effects from the group-mean DOLS certainly provide important knowledge to the governments and policy makers; however, they do not indicate the direction of Granger causality among the analyzed panel data. It is also interest for researchers to expose the causal relationship between CO_2 emissions, real output, the quadratic real output, renewable and non-renewable energy, and trade openness. For this purpose, this study would rather apply the bootstrap panel Granger causality test developed by Emirmahmutoglu and Kose [83] than traditional panel Granger causality techniques because the Emirmahmutoglu-Kose approach accounts for both issues of cross-sectional dependence and heterogeneity. Therefore, it is assumed to produce reliable causal linkages among the analyzed variables.

Results from the Emirmahmutoglu-Kose Granger causality test are given in Table 7. There is sufficient evidence to report that there is bidirectional Granger causality between real income and carbon emissions. Besides, we find the presence of unidirectional causality running from environmental degradation to renewable energy, from non-renewable energy to the pollution, from carbon emissions to trade openness from real income to renewable energy, from openness to real output, from trade openness to renewable energy, from non-renewable energy to trade openness, and from non-renewable energy to renewable energy. The overall result is consistent with Apergis et al. [14]; Menyah and Wolde-Rufael [84]; Pao and Tsai [53]; Shahbaz et al. [82]; Sulaiman et al. [80]; Sulaiman et al. [85]; Chandran and Tang [74]; Kasman and Duman [86]; Tang and Tan [48]; Dogan and Turkekul [20]; Apergis and Payne [87]; and Ben Jebli et al. [58].

5. Conclusion and policy implications

The contribution of this study to the already well-researched topic of the EKC hypothesis and the determinants of the emissions of various countries is multiple. Firstly, the continent of Africa was not the focus of many studies due to its low levels of emissions in the past; however, the Sub-Saharan Africa is among the most vulnerable regions to climatic change due to the nature of the economy. Secondly, there is no other study on the Sub-Saharan African countries that examines the differences of the impact of renewable versus non-renewable energies on the emission level of the countries. Next, the majority of studies use panel methods but ignore cross-sectional dependence, which in the case of Africa is crucial. The study acknowledges the fact that emissions are a major environmental issue currently faced by the world but not the only one. The use of renewable energies to substitute for fossil fuels is not a panacea to all environmental problems. They too have a certain impact to the environment. The particular size and type of

Table 7
Results from Emirmahmutoglu-Kose Granger causality test.

Hypothesis	Fisher-statistic	p-value	Direction of causality
$\ln GDP(\ln GDP^2) \rightarrow \ln CO_2$	36.28***	0.01	Two-way causality between lnGDP and $\ln CO_2$
$\ln CO_2 \rightarrow \ln GDP(\ln GDP^2)$	35.05**	0.02	
$\ln REN \rightarrow \ln CO_2$	20.94	0.40	One-way causality from lnCO2 to lnREN
$\ln CO_2 \rightarrow \ln REN$	37.14***	0.01	
$\ln NREN \rightarrow \ln CO_2$	29.76*	0.07	One-way causality between lnNREN to $\ln CO_2$
$\ln CO_2 \rightarrow \ln NREN$	18.5	0.55	
$\ln TO \rightarrow \ln CO_2$	22.15	0.33	One-way causality between $\ln CO_2$ to lnTO
$\ln CO_2 \rightarrow \ln TO$	36.95***	0.01	
$\ln REN \rightarrow \ln GDP(\ln GDP^2)$	24.06	0.23	One-way causality from lnGDP to lnREN
$\ln GDP(\ln GDP^2) \rightarrow \ln REN$	41.84***	0.00	
$\ln NREN \rightarrow \ln GDP(\ln GDP^2)$	11.93	0.91	No causality between lnGDP and lnNREN
$\ln GDP(\ln GDP^2) \rightarrow \ln NREN$	25.6	0.17	
$\ln TO \rightarrow \ln GDP(\ln GDP^2)$	39.78***	0.00	One-way causality from lnTO to lnGDP
$\ln GDP(\ln GDP^2) \rightarrow \ln TO$	27.52	0.12	
$\ln REN \rightarrow \ln TO$	27.4	0.12	One-way causality from lnTO to lnREN
$\ln TO \rightarrow \ln REN$	29.71*	0.07	
$\ln NREN \rightarrow \ln TO$	30.35*	0.06	One-way causality from lnNREN to lnTO
$\ln TO \rightarrow \ln NREN$	15.76	0.73	
$\ln REN \rightarrow \ln NREN$	25.06	0.19	One-way causality from lnNREN to lnREN
$\ln NREN \rightarrow \ln REN$	28.73*	0.09	

Note: ***, ** and * denote the statistical significance at 1%, 5% and 10% levels.

impact depends highly on the technology, the location geographically, and the availability of resources [88]. Excessive use of depleted resources might also be considered in the narrative.

Al-Mulali et al. [1,21,22]; argues that the EKC hypothesis does not hold for the poor countries, because they have not most probably reached the threshold income level for the emission levels to start decreasing. Another explanation for this is the nature of the developing or poor countries that are abundant in fossil fuel resources and hence, power generation from particularly coal is cost-effective. Hence, the transition to renewable energies and the "right-hand side of the EKC" (leapfrogging) is challenging for developing countries, or as Murphy [23] points out especially for the rural East Africa. In addition, African countries have to deal with immediate problems of declining power systems in combination with significant lack of access to energy for most of the rural areas. This is another reason why environmental friendly policies were not a priority in the agenda of African countries. Based on this analysis, it is imperative to investigate the dynamics between pollution and economic development in the most crucial from an energy point of view Sub-Saharan African countries.

The findings of this study can be summarized as follows.

- Both panel cointegration tests confirm that CO_2 emissions, real income, the square of real income, renewable and non-renewable energy, and trade openness are cointegrated and thus have a long-run relationship for the top 10 African countries.
- The elasticities of CO_2 emissions with respect to renewable and non-renewable energy are 0.34% and −0.17%, respectively. This indicates that increases in non-renewable energy consumption increase the pollution while increases in renewable energy consumption drive down environmental degradation.
- The elasticity of carbon emissions with respect to trade openness is −0.12%. This implies that increases in trade openness help reduce the level of CO_2 emissions for the top energy generators in Sub-Saharan Africa.
- With regards to direction of causal relationships, we observe a unidirectional causality running from environmental degradation to renewable energy, from non-renewable energy to the pollution, from carbon emissions to trade openness from real income to renewable energy, from openness to real output, from trade openness to renewable energy, from non-renewable energy to trade openness, and from non-renewable energy to renewable energy.

It stems from the results that increasing the share of coal and other non-renewable energy types in the supply energy mix of the ten countries will increase the air pollution of the region; while the choice of renewable energies will have a significant positive effect to the air cleanliness. The top 10 Sub-Saharan countries are strongly suggested to stimulate the use of energy from renewable sources and mitigate the use of energy from non-renewable sources so as to reach lower level of emissions.

Some of the causal relationships and their directions of our findings are not unique or specific in the Sub-Saharan geographical area, for example the fact that environmental degradation to renewable energy. The importance however of non-renewable sources can be explained by the vast unexploited reserves of fossil fuels in the continent and hence the prospects still for increases in fossil fuel supply. However, it is confirmed from our findings that this will burden the continent with higher levels of pollution and further negative consequences stemming from climate change.

Increases in income will lead to higher renewable energies in the country group. In the current economic and financial conditions in the continent and around the world, the higher debt burden and the volatility of sub-Saharan African currencies leave little room for investments [25] and clean energy development does not seem to be a priority in the political agenda. However, as soon as economic growth picks up, according to our results, that will lead to higher supply and use of renewable energies.

Finally, the importance of trade openness for economic growth as well as renewable energies has a multiple important meaning. Initially, it stresses the cross-dependence intuition among Sub-Saharan African countries. Each of these countries have shown a critical development of local energy expertise wiling to deal with the challenge of developing and implementing appropriate programs, strategies and policies. In their vast majority, both Governments and local energy experts and policy makers have agreed in the importance of linking in a bigger network the countries of southern Africa. The reason behind this way of thinking is the unequal distribution of natural resources in the continent. So as pointed out by Karekezi [25] better networking, information and skills exchange as well as trading of resources and technologies is crucial for the energy and environmental future of the continent, as it is also shown by our findings.

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